Characteristics of Interconnects on FR408 at Millimeter-Wave Frequencies

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Characteristics of Interconnects on FR408 at Millimeter-Wave Frequencies

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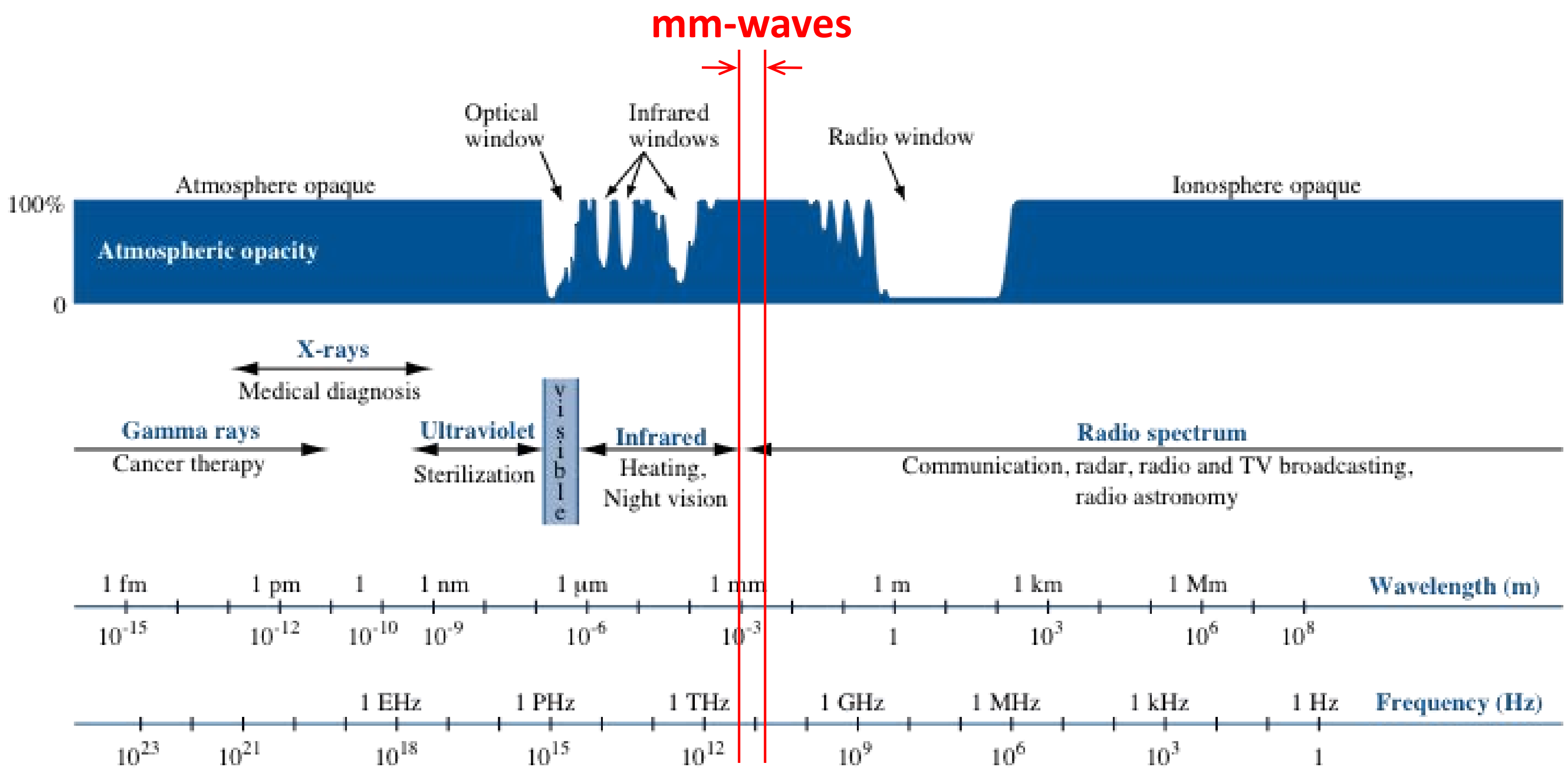
Presentation Outline

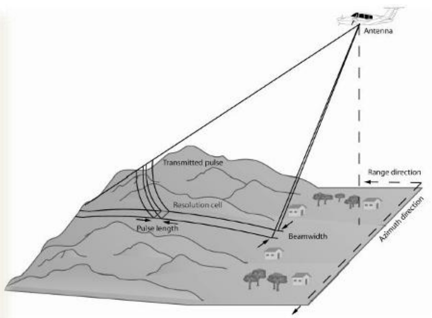
- Motivation
  - CMOS and Millimeter-Wave Applications
  - System-in-package solution
- Why FR408?
- Interconnect Design
  - Coplanar Waveguide (CPW)
  - Microstrip
- Fabrication
- Measurements and Results
  - CPW
  - Microstrip with measurement probe pads
- Summary of results
- Conclusion
- Future Work

Millimeter-wave Frequencies

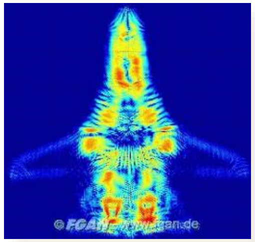
- Millimeter (mm-wave) Frequencies (60GHz to 300GHz)
  - $\lambda = c/f$
    - 5mm at 60GHz, 1mm at 300GHz



CMOS and Millimeter-Wave Applications

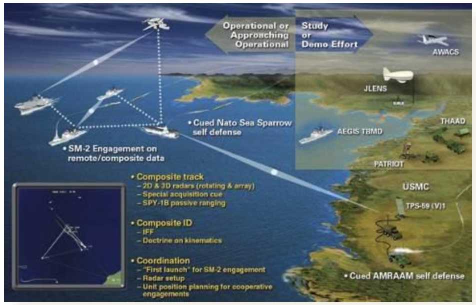


- UAV



- Imaging

- Automotive Radar

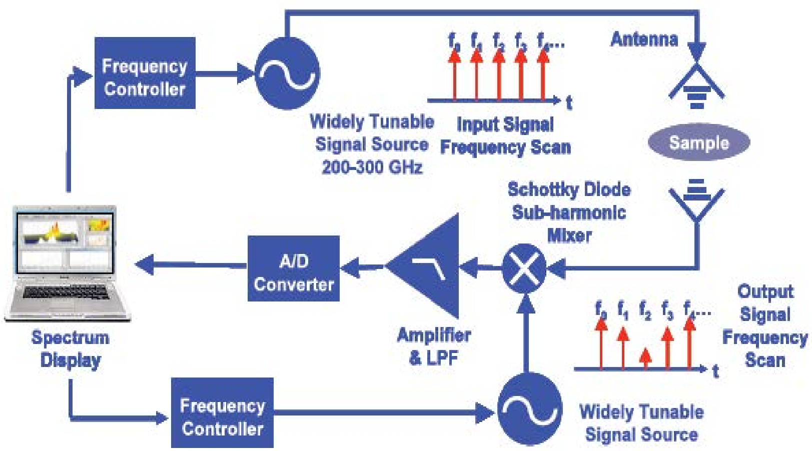


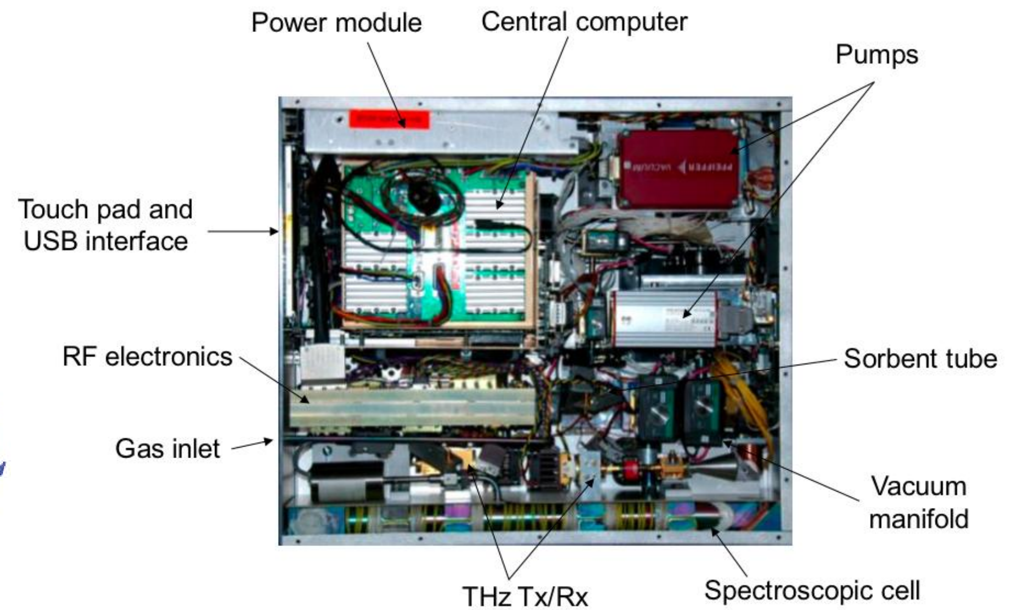
- Secured High Throughput Link

- Through wall surveillance

Motivation

- CMOS and Millimeter-Wave Applications
  - Gas spectrometer- 180-300 GHz



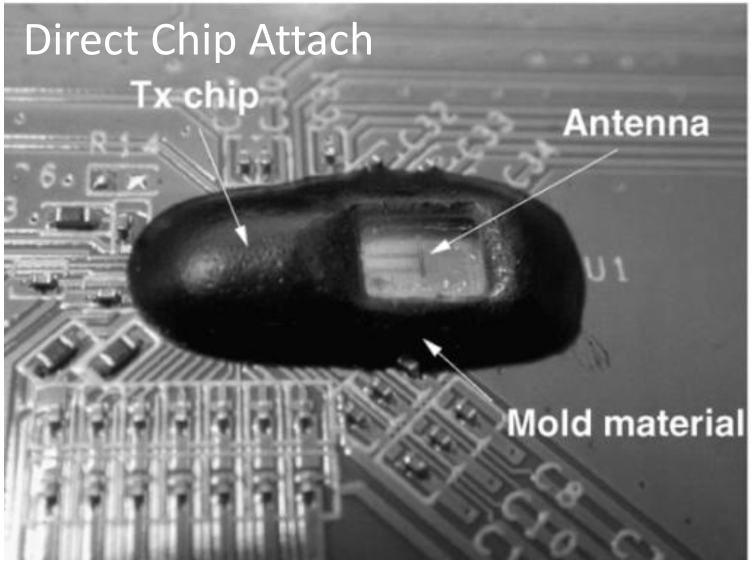


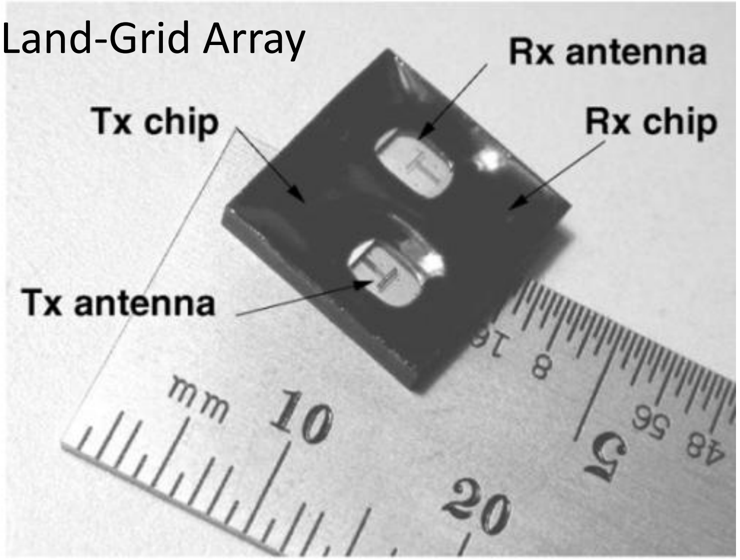
Gas Spectrometer Currently Implemented with Waveguide and Horn Antennas

- System-in-package solution
  - FR408

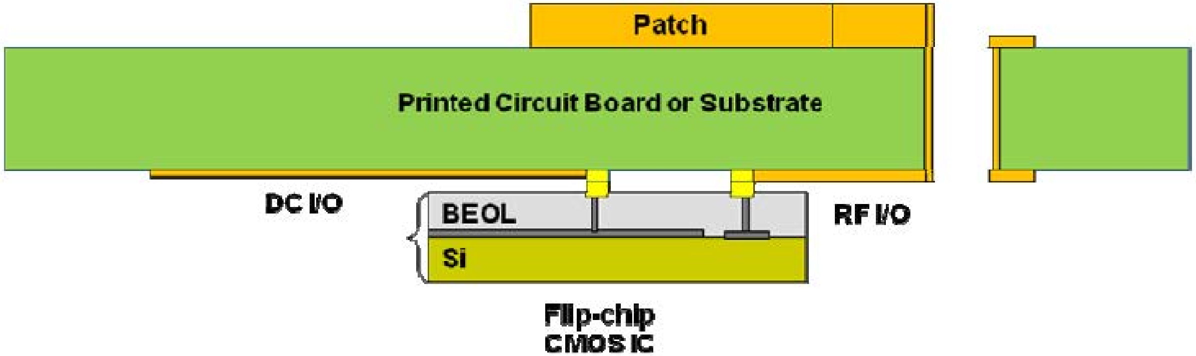
Antenna in-package Strategies

60 GHz IBM Approach



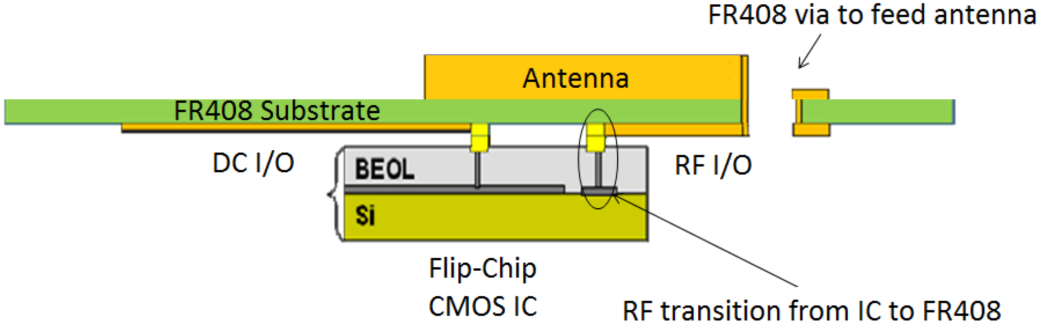


UTD Approach



In-package Strategy

- Material – FR408
- Process development – Special etch technique to realize feature sizes needed for mm-wave
- Interconnect study – best performing
- Integration
  - Attach silicon die to FR408
  - Use vias or EM coupling to transfer signal to antenna

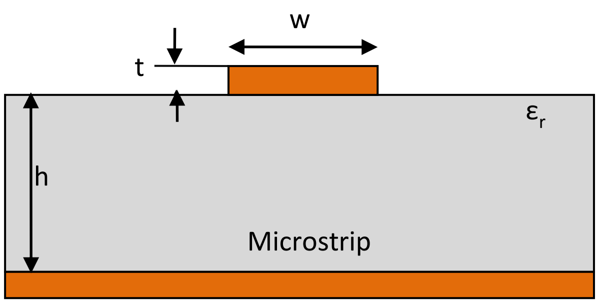


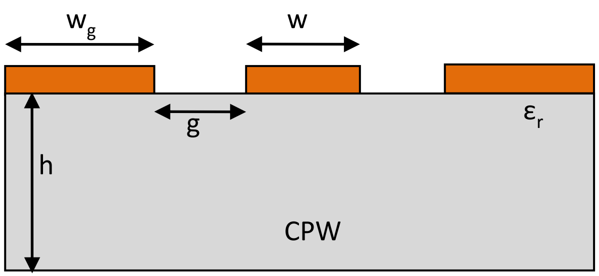
Why FR408?

Substrate Material	Cost	Dielectric Constant	Loss tangent
FR4 G10 Laminate	X	4.2	0.02
FR408 Laminate	1.5X	3.65	0.013
RT Duroid 5880	20X	2.2	0.0009

- Low cost
- Better Performance
- Dielectric Thickness : 125 μm
- Copper Thickness: 17 μm, double- sided
- Bulk Conductivity: 2.17 e-12 S/m

Interconnect Design

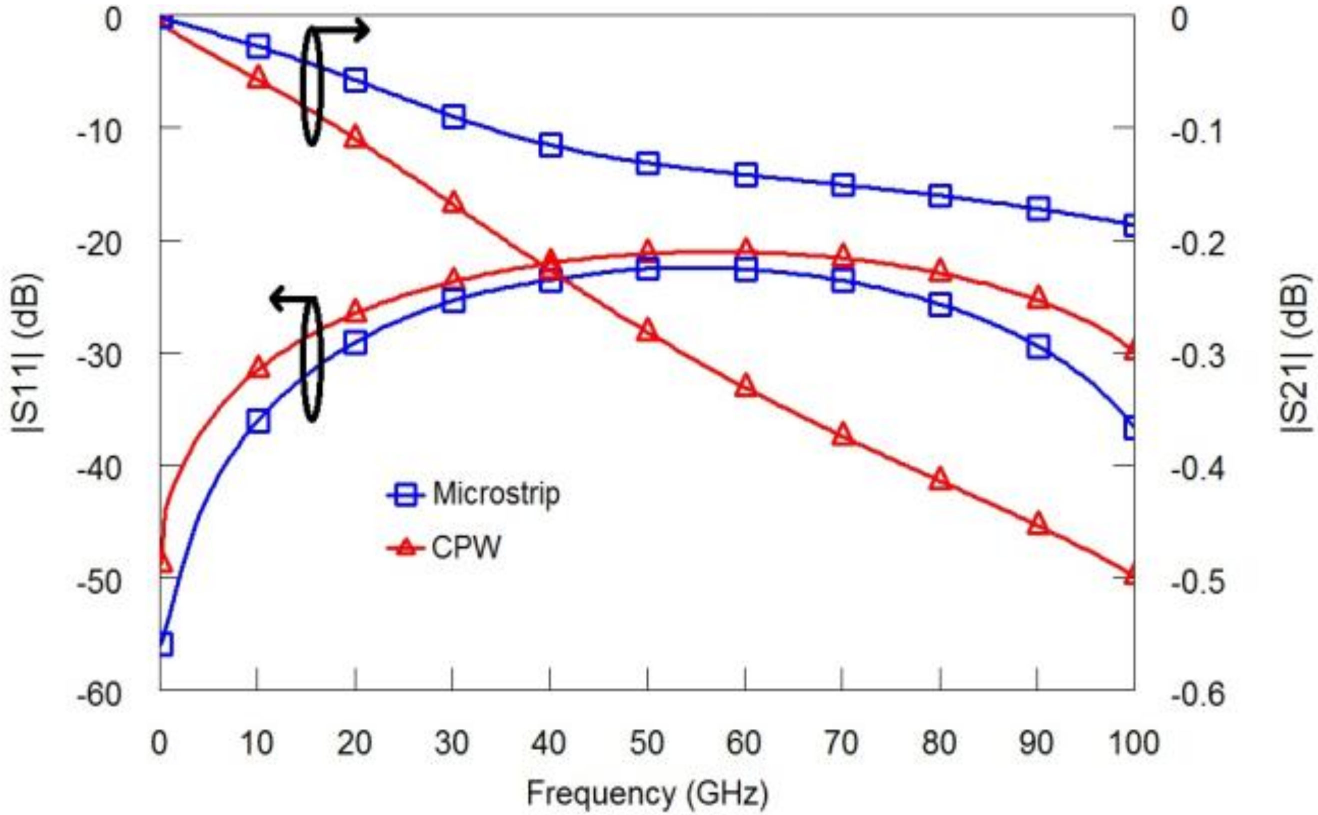




h= 125 µm; t= 17 µm; ε_r= 3.65

TML	Width(w) (µm)	Gap (g) (µm)	Z_0 (Ω)
Microstrip-1	264.5	-	50
Microstrip-2	273	-	49
CPW – 1	75	20	51
CPW – 2	140	25	50
CPW – 3	150	25	49
CPW – 4	45	15	50

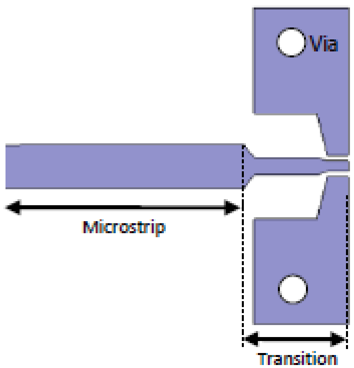
Simulation Results of FR408 Interconnects

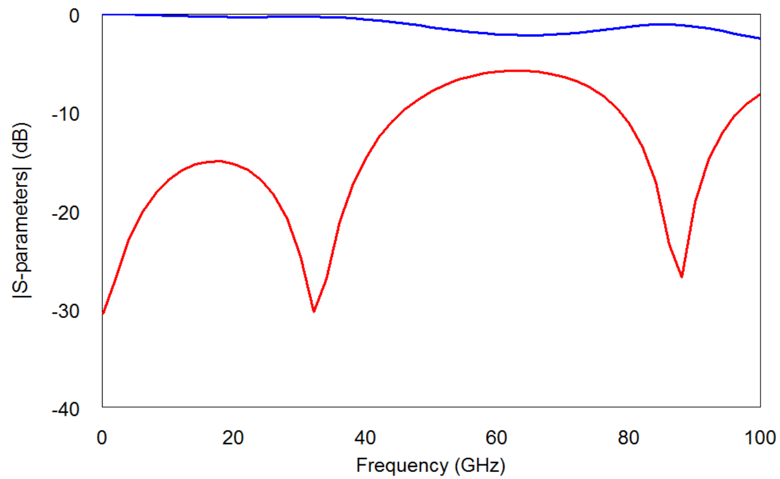


- HFSS simulated S-parameters for 50 Ω CPW-1 and microstrip-1 lines. Line length is 1mm.
- Return loss for both lines is comparable at below 20 dB.
- Insertion loss for CPW is greater than that of microstrip.

Microstrip Transitions for Measurement

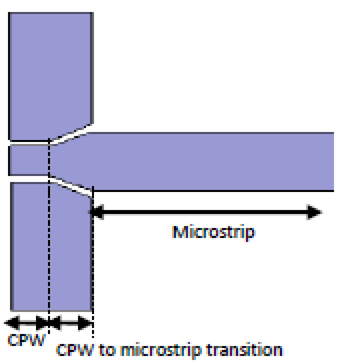
- Transition with vias to ground filled with epoxy.

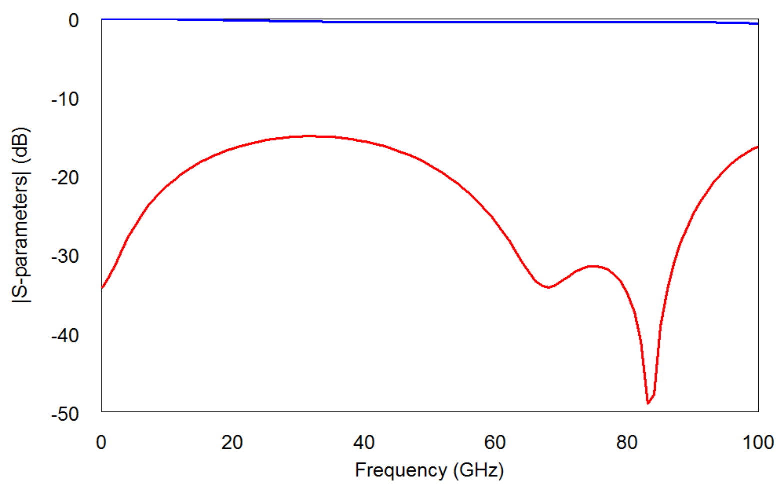




Total Length = 2 mm
Transition dimensions:
Transition length = 500 µm
Via diameter = 150 µm
Microstrip dimensions:
w = 273 µm
l = 1 mm

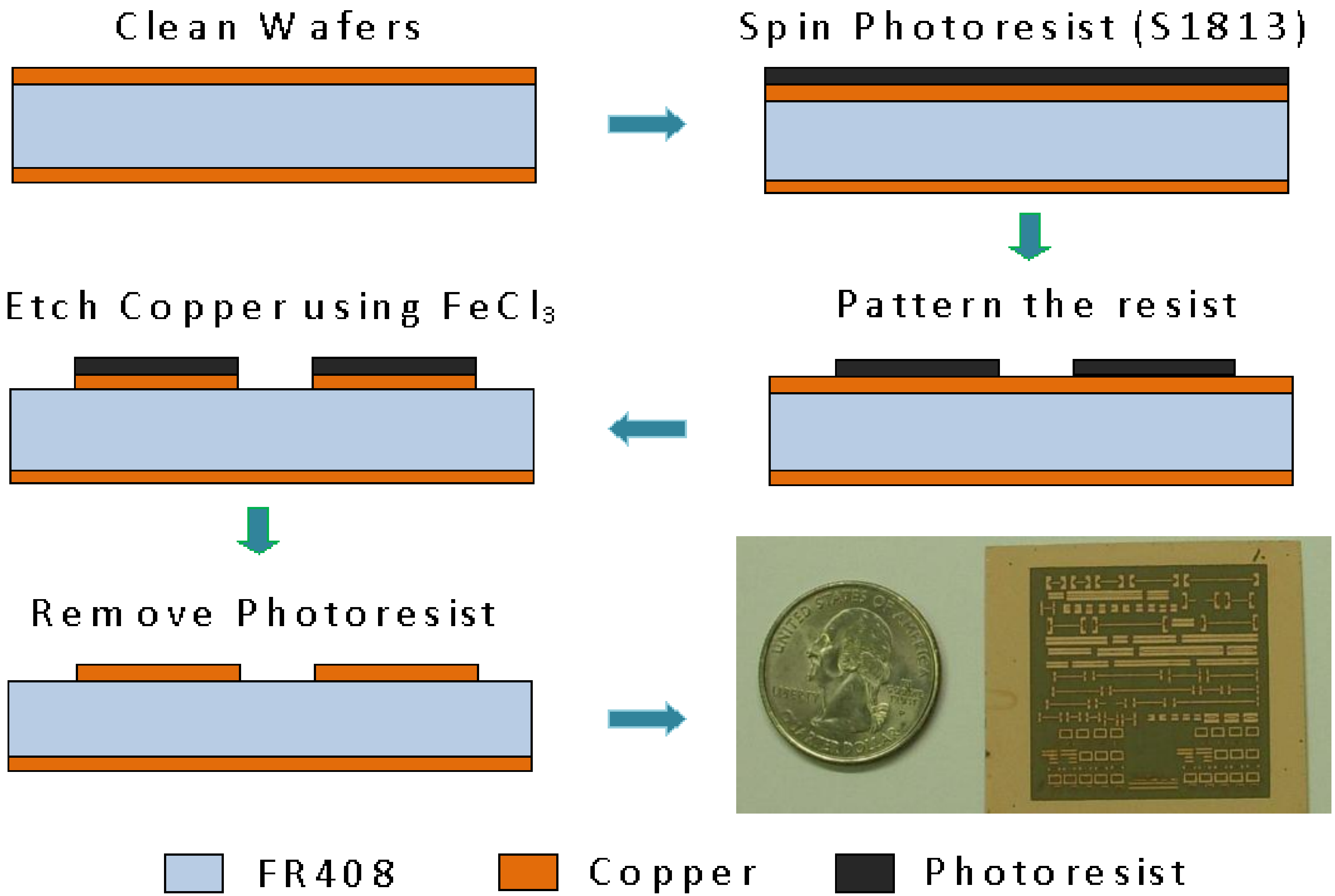
- Vialess transition based on [1].





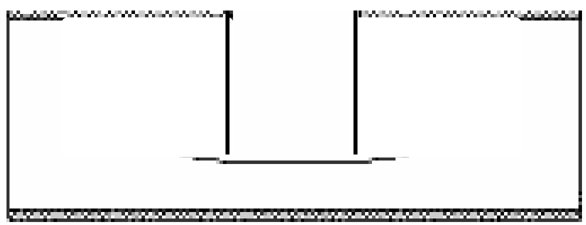
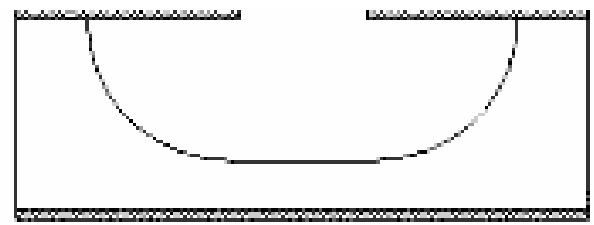
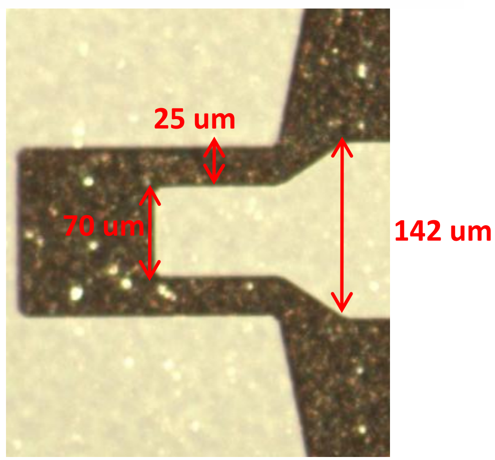
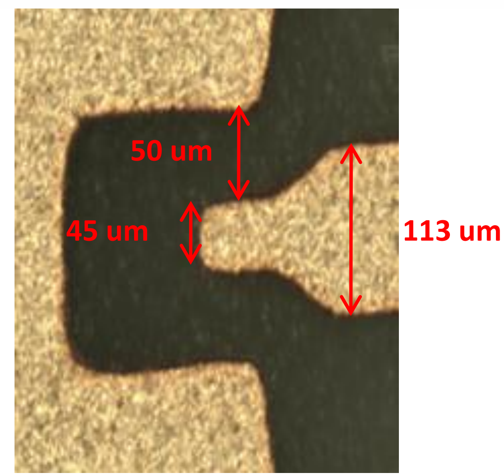
Total Length = 1.4 mm
CPW dimensions:
w = 140 µm
g = 25 µm
CPW transition = 100 µm
Microstrip dimensions:
w = 264.5 µm
l = 1 mm

Fabrication Flow



Fabrication

Isotropic wet etch causes undercut due to simultaneous horizontal and vertical etching.

	Ideal	Realized
Side-view		
Top-view		
	Microstrip with epoxy transition before removing photoresist layer	Microstrip with epoxy transition after removing photoresist layer

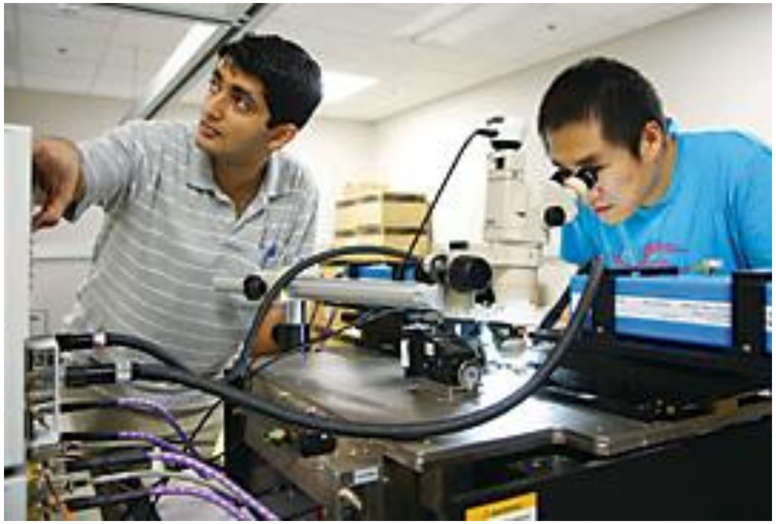
Fabrication Results

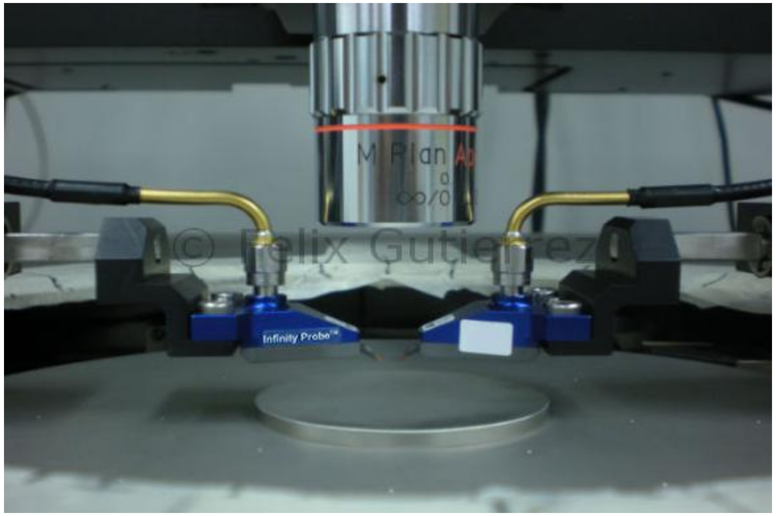
	Simulated Geometries			Fabricated Geometries			
TML	Width (µm)	Gap (µm)	Z_0 (Ω)	Width (µm)	Gap (µm)	Z_0(Ω)	Z_0 % diff
Microstrip-1	264.5	-	50	242.5	-	52.5	5 %
Microstrip-2	273	-	49	252	-	51.3	3 %
CPW – 1	75	20	51	60	40	70	37 %
CPW – 2	140	25	50	118	49	63	26 %
CPW – 3	150	25	49	135	40	54	10 %
CPW – 4	45	15	50	20	40	85	70 %

- Center line widths are narrower by 15-25 µm and the gaps are 10-20 µm wider
- Higher characteristic impedance

Measurement

- Measurements up to 67 GHz
- Probe station with Agilent E8361A PNA

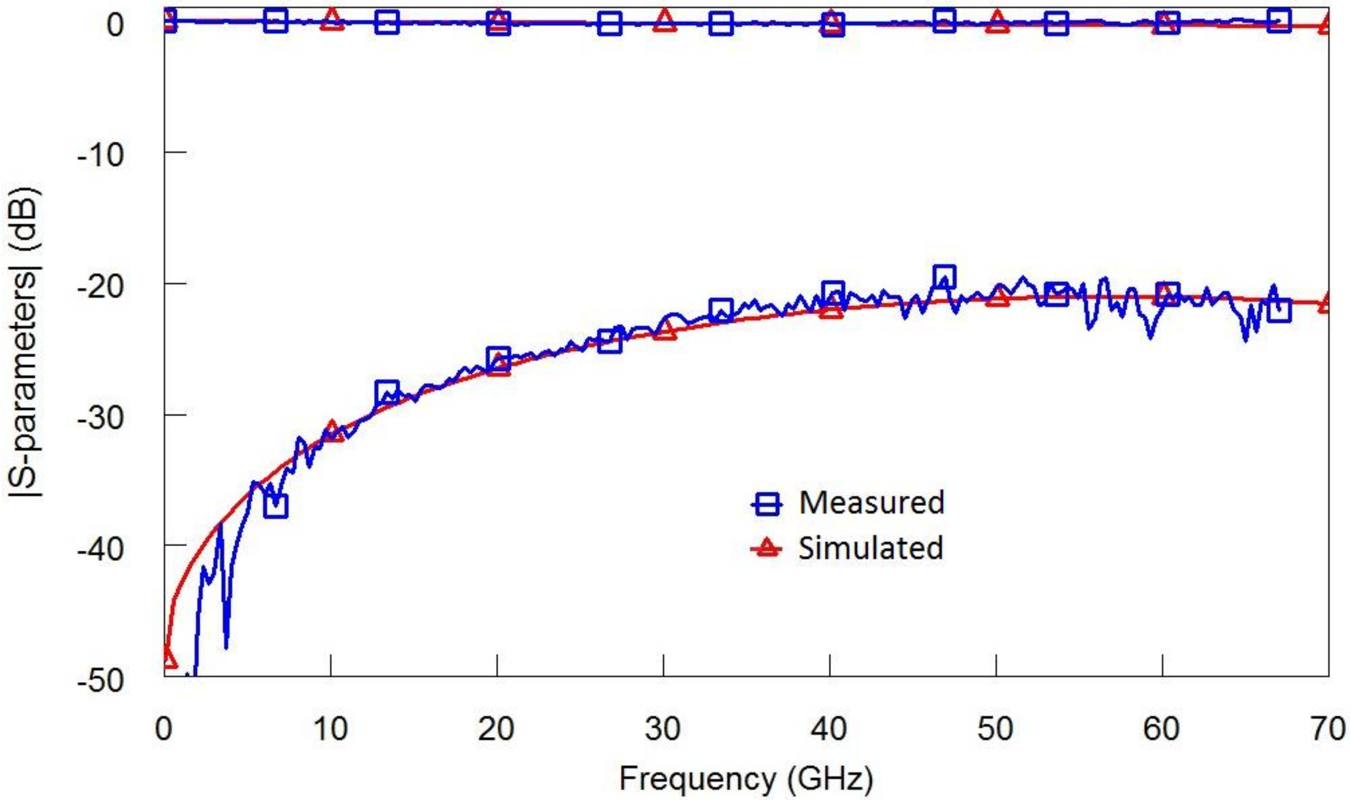




- Calibration type: 2-port SOLT
- Probes: GGB ground-signal-ground probes with 150 µm pitch

CPW Results

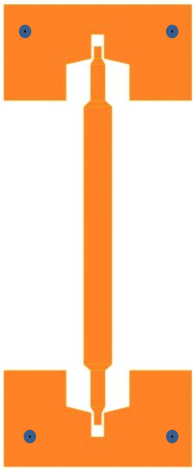
Measured vs. Simulated results for 1 mm long CPW-3 line

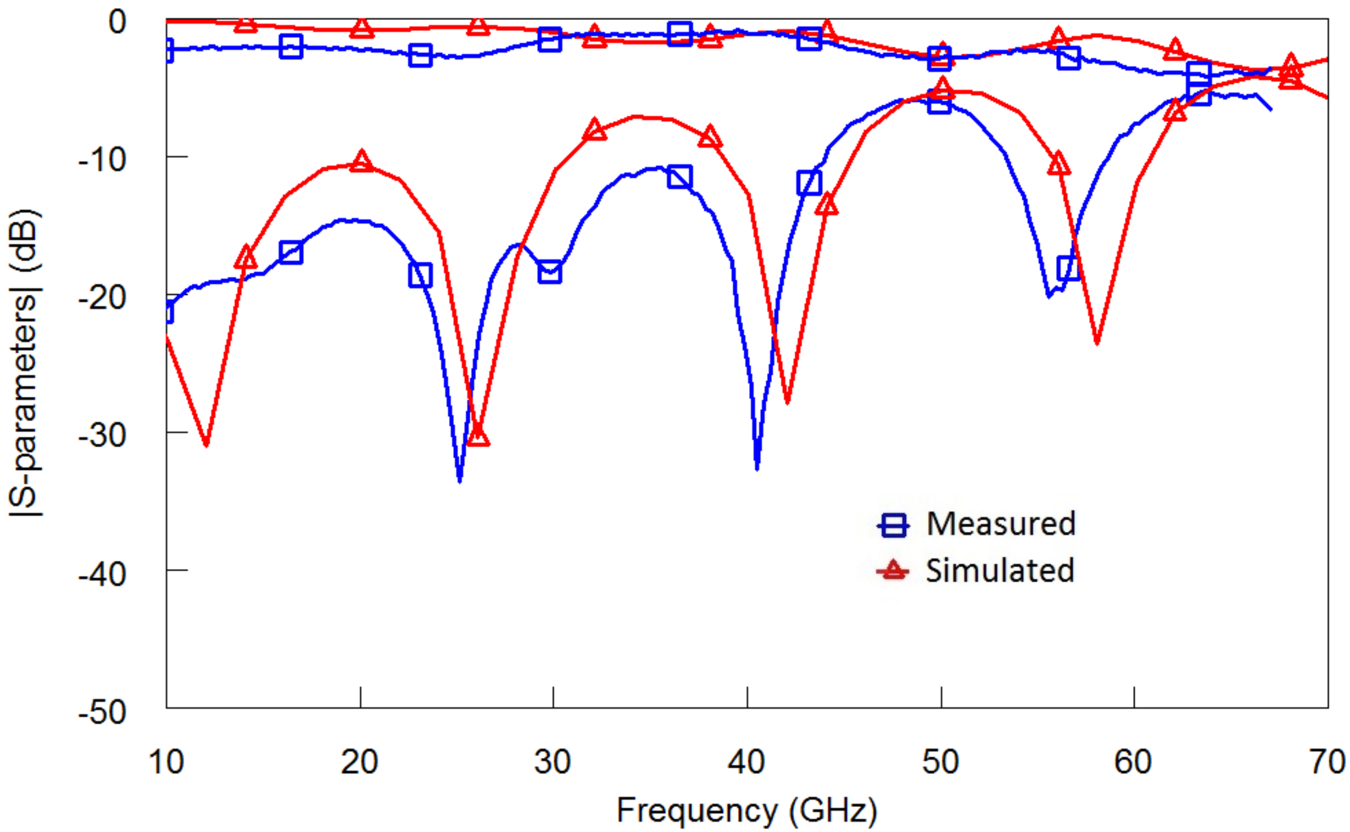


- Return loss of 20 dB or better and insertion loss of 0.27 dB or better.
- Good agreement between simulation and measurement.

Microstrip w/Epoxy Results

Measured vs. Simulated results for 4.82 mm long microstrip

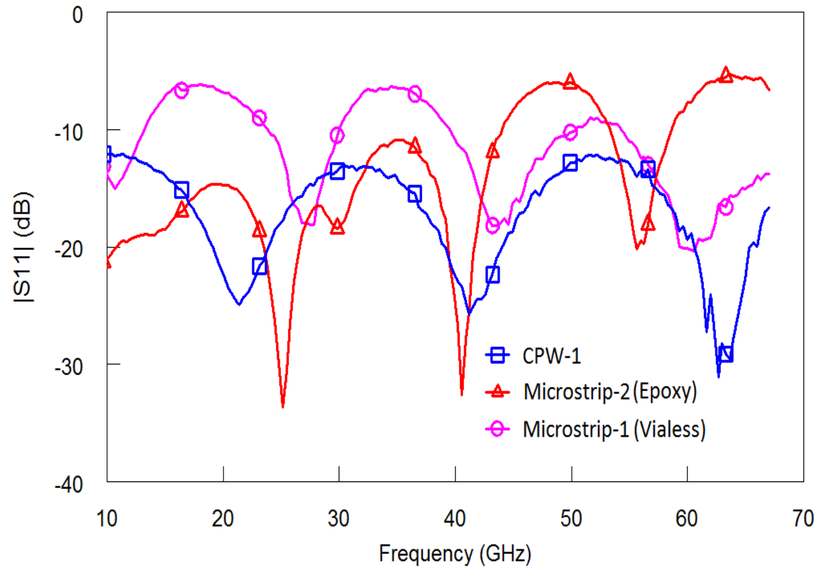


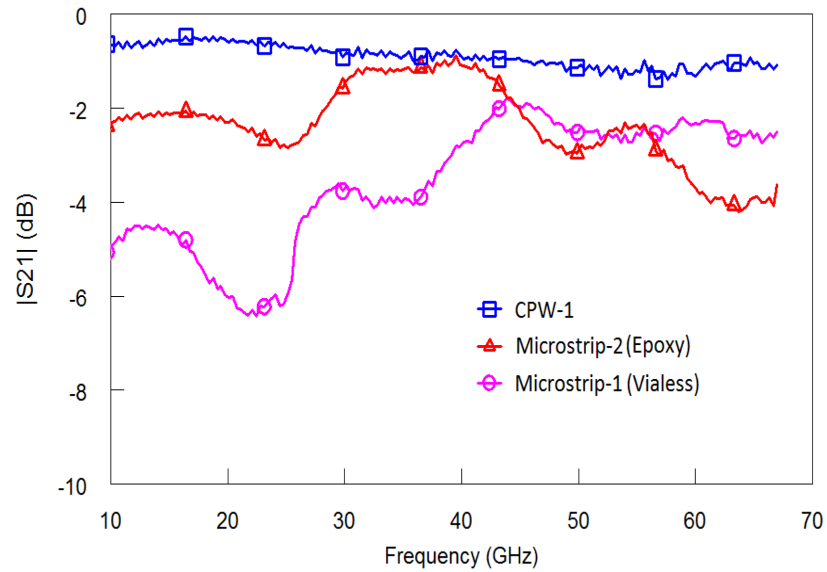


- 6 mils drill bit and silver epoxy used to create vias to ground.
- Simulation with fabricated geometry for microstrip-2 line.
- Good agreement between simulation and measurement.

Overall Comparison

$|S_{11}|$ (dB) and $|S_{21}|$ (dB) for 4.82 mm long lines





Loss/mm for FR408 lines at 60 GHz

Line	CPW-1	Vialess	Epoxy
$|S_{21}|$/mm (dB)	0.25	0.48	0.76
Z_0 Ω	70	51.3	52.5

Attenuation/mm for 50 Ω lines at 60 GHz

Line	GaAs	CMOS with p+ doping	CMOS with 8 µm BCB layer	Duroid
Att./mm (dB)	0.09	1.6	0.96	0.07

Conclusion about this work

- CPW and microstrip transmission lines have been simulated, fabricated and measured up to 67 GHz.
- Measured results show that CPW lines have an insertion loss of about 0.2 dB/mm.
- Microstrip line measurements suffer from transition effects. Measured results show that the vialess transition perform at higher frequencies.
- FR408 is a viable candidate for interconnects when short line lengths are utilized .

Future Work

- Simulation – Extended study of CPW to microstrip transition design
- Design – Add de-embedding structures for microstrip
- Fabrication – Account for isotropic etch to improve realized geometries
- Measurement – Extend the frequency range and extract propagation and attenuation constant

References

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Thank you.